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University Programs of the U.S. Advanced Fuel Cycle Initiative
Fiscal Year 2003 Annual Report

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Abstract–*The Advanced Accelerator Applications (AAA) Program of the U.S. Department of Energy (DOE), which was initiated in fiscal year 2001 (FY01), grew and transitioned to the Advanced Fuel Cycle Initiative (AFCI) in FY03. Because of past and projected future growth of this program as well as the Nuclear Power 2010 and Generation IV nuclear programs of the DOE, research for nuclear science and technology will require an ever-larger cadre of educated scientists and trained technicians. In addition, other applications of nuclear science and engineering proliferation monitoring and defense, nuclear medicine, safety regulation, industrial processes, and others require increased academic and national infrastructure and even larger student populations. Because of the early recognition of education requirements, beginning with the predecessor of AAA and AFCI, the Accelerator—driven Transmutation of Waste Project (ATW), the DOE Office of Nuclear Energy, Science and Technology began a multi-year university program. This program was created to involve university faculty and students in various phases of the ATW, AAA, and AFCI Programs. This education program is not solely to educate students, however; it has also supported the infrastructure requirements of nuclear energy, science and technology fields as well as the special needs of the DOE transmutation research program. In this report I summarize the goals and accomplishments of the university programs that have supported the ATW, AAA and AFCI Programs during FY03, including the involvement of 140 students and 67 faculty and research staff members, 27 universities in the U.S. and abroad, and the publication and presentation of more than 100 papers cited herein.*

I. INTRODUCTION

Large-scale research for P&T technology P _artitioning of used nuclear fuel and Transmutation of its resultant wastes began in the U.S. in the early 1990s as a Laboratory Directed Research and Development (LDRD) Project at the Los Alamos National Laboratory (LANL). Researchers at LANL first examined molten-salt fueled and cooled systems for Accelerator-driven Transmutation of Waste (ATW), and later investigated liquid-metal-cooled, metal-fueled ATW concepts. The National Academy of Sciences reviewed ATW and other concepts as a means of managing used nuclear fuel in the mid-1990s,[1] and the Department of Nuclear Engineering at the Massachusetts Institute of Technology reviewed the ATW LDRD project of LANL again in 1998. After the MIT review the U.S. Congress recognized the potential of this technology for managing a large legacy of used nuclear fuel; they then authorized the Office of Environmental Management of the U.S. Department of Energy (DOE-RW, Office of Civilian Radioactive Waste Management-OCRWM) to develop a technology and deployment roadmap for ATW in Fiscal Year 1999 (FY99). Following a successful national effort to complete a roadmap and a Report to Congress,[2] the Congress then funded an ATW research program within the Office of Nuclear Energy, Science and Technology (DOE-NE) beginning in FY00.

A year after the completion of the ATW Roadmap, the Advanced Accelerator Applications (AAA) Program was initiated as a multi-laboratory research program in collaboration with a number of universities, including the University of Nevada, Las Vegas, the University of California at Berkeley, the University of Michigan, and the University of Texas at Austin. The primary mission of the AAA Program was the development of technology for transmutation of nuclear waste and demonstration of its practicality and value for long-term waste management. Other goals were to help revitalize the U.S. nuclear

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infrastructure and for the U.S. to resume an international leadership role in nuclear technologies. Research for new transmutation science and technology will require a large cadre of educated scientists and trained technicians in addition to that required for our broader national nuclear infrastructure.[3, 4] In FY03, the AAA program again transitioned to a new program called the Advanced Fuel Cycle Initiative (AFCI), with a larger goal of integration and management of nuclear materials in the entire existing as well as future fuel cycles. This larger program will require an even larger involvement of academia and students than did the ATW and AAA projects.

During the next decade, the nation will need additional nuclear scientists and engineers for national security programs that include counter-proliferation, global monitoring, stewardship of our nuclear stockpile, and naval nuclear propulsion. We will also need more college graduates for design and federal regulation of Generation IV reactors and advanced fuel cycles, and we will need young people for nuclear medicine and medical research using radioisotopes. We will need still more young scientists and engineers for expanding industrial radiation applications such as manufacturing, oil and gas exploration, and irradiation to sterilize hundreds of consumer products and most medical equipment. In addition, we ll need a larger nuclear workforce to design and operate irradiation facilities to eliminate pathogens like Listeria and E. coli from our food, Hoof-and-mouth from our feed stocks, and Anthrax from our mail.

Because of the requirements for educated scientists and engineers in a wide variety of nuclear- and accelerator-related fields, the DOE-NE and the national laboratories created multi-year programs to involve university faculty and students in various phases of the ATW, then the AAA, and now the AFCI Programs. In this report I describe ongoing university programs that are supporting both the research needed to support the national nuclear infrastructure and to develop P&T technology. Since the inception of the LANL-funded ATW project, LANL has taken the lead in these programs in funding, coordinating, and collaborating on research involving faculty and students. These past programs included research projects at the University of Michigan, the University of California at Berkeley, and the University of Texas at Austin; a University Participation Program (AAA UPP) at the University of Nevada, Las Vegas (UNLV); and a University Fellowship Program (AAA UFP). Current programs include ongoing LANL-funded university research, including more universities that were added in FY03 for a total of nine directed-university research projects; the UNLV program, which has been renamed the UNLV Transmutation Research Program (TRP); continuation of the AFCI Fellowship Program; and the AFCI Project at the Idaho State University Idaho Accelerator Center (ISU-IAC). I begin this report with a description of student support during the year, and subsequent sections of the report contain detailed descriptions of research programs at the universities.

II. AFCI ACADEMIC SUPPORT

A significant aspect of these Programs is that during the past five years they have supported more than two hundred U.S. students. During FY03 140 students were supported through the University Fellowship Program, research contracts with 11 universities, and graduate research assistantships and internship programs at national laboratories. Both FY02 AAA and FY03 AFCI funding was used for this support. Table I is a summary of the different categories of student support. Subsequent sections of this report include brief descriptions of these programs. The universities students worked at or came from to work at national laboratories are included in Table II.

Table I. Summary of FY03 AFCI Student Support*

UNLV Transmutation Research Program	76	(56 graduate and 20 undergraduate students)
ISU-IAC Program	16	(10 graduate and 6 undergraduate students)
University Fellowship Program	20	(8 FY01 and 10 FY02)
Directed University Research Programs	20	(16 graduate and 4 undergraduate students)
Laboratory interns and graduate research assistants	19	(includes students also in other categories)

*Some students are counted in more than one category, e.g. Fellows worked as GRAs at Los Alamos, Oak Ridge, and Argonne National Laboratories.

III. UNIVERSITY OF NEVADA, LAS VEGAS TRANSMUTATION RESEARCH PROGRAM (TRP)

The UNLV TRP was designed to benefit the National AFCI Project and the University s goals to enhance student-focused and internationally recognized research programs. In accordance with the public law that established the AAA Project and UNLV funding in FY01, the purpose of the UNLV TRP was to conduct research and development of technologies for economic and environmentally sound refinement of used nuclear fuel. In its first year, 12 research projects were initiated, and that list expanded to 16 during FY02. In addition, substantial improvements to infrastructure at the UNLV are underway. During the past year 76 students have been employed at UNLV in research projects and as support to the project administrators in the Harry Reid Center for Environmental Studies. These students represent several colleges at UNLV, including Health Sciences, Engineering, and Sciences, and several departments within those colleges. Discussions of the sixteen approved research projects, infrastructure improvements, and faculty augmentation are in the first and second TRP Annual Reports.[5, 6] The research projects at UNLV are highly interdisciplinary, cutting across departments and even colleges. With the UNLV TRP now in its third year with more than 30 faculty and research staff, the UNLV has become the lead university for transmutation research in the U.S. Their presence with the project has also increased its visibility in the media.[7]

The Director of the UNLV TRP has provided quarterly reports, has submitted overview reports to national conferences,[8] and has given presentations at reviews and national meetings that describe the vision and implementation of this rapidly maturing program. These presentations and reports include descriptions of the research projects that were underway in the first two years of the program, important decision points, and a description of a new paradigm in research collaborations with national laboratories that is exemplified by the program. A brief description of each of the projects will illustrate the breadth of ongoing transmutation research at UNLV (leading numerals coincide with UNLV Task numbers):

1. Melt casting of metallic fuel pins incorporating volatile actinides.[9, 10, 11]
2. Modeling, fabrication, and optimization of niobium accelerator cavities.[12, 13]
3. Experimental investigation of steel corrosion in lead bismuth eutectic.[14, 15, 16, 17,18] UNLV graduate student Mr. Dan Koury completed a thesis project while using scanning electron microscopy and x-ray photoelectron spectroscopy to examine steel samples; he was graduated with the M.S. degree in physics in Dec. 2002.[19] Another student, Ms. Denise Parsons, earned her B.A. in biology while working on this project as an undergraduate student.
4. Hydrogen-induced embrittlement of candidate target materials.[20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30]

Table II. FY03 AFCI Universities.*

Alcorn State University	Ohio State University	University of Leoben, Austria
Arizona State University	Oregon State University	University of Massachusetts
Brigham Young University	Purdue University	University of Michigan
Colorado School of Mines	South Dakota School of Mines & Technology	University of Nevada, Las Vegas
Georgia Institute of Technology	Texas A&M University	University of New Mexico
Idaho State University	University of California, Berkeley	University of Tennessee, Knoxville
Imperial College of London	University of Florida	University of Texas, Arlington
North Carolina State University	University of Illinois, Urbana-Champaign	University of Texas, Austin
New Mexico Institute of Technology		Westminster College
Northern Illinois University		

*Students worked at these universities or came from these universities to work as graduate research assistants at national laboratories during Fiscal Year 2003.

UNLV student Mr. Mohammad Hossain received the Outstanding Paper Award at the 2003 American Nuclear Society (ANS) Student Conference for his paper on stress corrosion cracking.[31]

5. Modeling corrosion in oxygen controlled LBE systems with coupling of chemical kinetics and hydrodynamics.[32, 33, 34, 35] UNLV student Mr. Chao Wu was graduated with the M.S.M.E. degree in July, 2003, while studying geometry effects on corrosion rates in LBE systems.[36]
6. Neutron multiplicity measurement for target/blanket materials. UNLV undergraduate student Mr. Dean Curtis was awarded Best Student Poster Paper for his presentation at the Sixth International Topical Meeting on the Nucl. Appl. of Accelerator Tech., (AccApp 03).[37]
7. UNLV leads a multi-university project to develop dose conversion coefficients for radionuclides produced in spallation neutron sources.[38, 39, 40] Mr. John Shanahan, a student in the Health Physics Department, was awarded the M.S. degree in July, 2003 after calculating a set of dose conversion coefficients.[41]
8. Systems engineering modeling of chemical separations.[42, 43, 44]
9. Design and evaluation of remote processes for fuel fabrication.[45, 46, 47, 48, 49, 50, 51]
10. Development of a mechanistic understanding of the high-temperature deformation of alloy EP-823. UNLV student Mr. Martin Lewis received a Best Paper Award at the ANS Student Conference.[52]
11. Nuclear criticality analyses for transmuter fuel fabrication and separations.[53]
12. Radiation transport modeling of beam-target experiments.[54, 55] Two UNLV students completed their M.S. in Mechanical Engineering degrees: Mr. Suresh Sadenini (Dec. 2002)[56] and Mr. Ashraf Kaboud (May 2003). In addition, Mr. Daniel Lowe, an undergraduate student, received an Outstanding Paper Award at the 2003 ANS Student Conference for his presentation on measurements from activation foils, a project he participated in at Los Alamos s LANSCE accelerator facility during the summer of 2002.[57]
13. Developing a sensing system for the measurement of oxygen concentration in liquid Pb-Bi eutectic.[58, 59]
14. Use of positron annihilation spectroscopy for stress-strain measurements (a collaboration with Idaho State University).[60, 61, 62, 63, 64, 65, 66]
15. Immobilization of fission iodine by reaction with a Fullerene-containing carbon compound and insoluble natural organic matrix to help develop waste forms for the back end of fluorine-based separations processes.
16. Evaluation of fluorapatite as a waste-form material.

IV. IDAHO STATE UNIVERSITY--IDAHO ACCELERATOR CENTER (ISU-IAC)

The AFCI Program at the Idaho Accelerator Center (IAC) of the Idaho State University (ISU) is now in its second year. The ISU-IAC AFCI Program was designed to benefit the National Project and the University s goals to enhance accelerator infrastructure and research. The AFCI program at ISU-IAC supports about twenty students annually. This project also includes three collaborations with UNLV, and one UNLV student worked in the IAC during the summer. The three research projects are:

Positron Annihilation for Materials Stress Analysis: A new technique for determination of residual stress in materials is being developed at the IAC in an intercollegiate project with UNLV faculty and students. These new techniques for Accelerator-based photon-induced Positron Annihilation Spectroscopy (AG-PAS) use highly penetrating photons (bremsstrahlung from high-energy electrons) to create positrons inside the material via pair production.[67, 68] Researchers at the IAC have also synchronized bremsstrahlung pulses with intense laser irradiation pulses to study dynamic structural changes in material as a result of thermally induced stress, where they have successfully measured stress/strain in engineering samples of several-cm thickness. These measurements have been completed on Steel, Aluminum, Zirconium and Silicon. In addition, they have developed another method using (p, gamma) reactions from a 2-MeV proton beam to perform positron lifetime spectroscopy.

Accelerator Driven Neutron Source: Staff and students at the IAC have developed and tested an electron accelerator-driven neutron source for performing dynamic reactivity measurements in multiplying and non-multiplying assemblies. The accelerator will provide a pulsed neutron fluence of about 10^{11} neutrons per pulse and an average of almost 10^{13} neutrons per second. The system has been constructed and experiments have been completed. Photo-neutron production calculations and benchmark experiments have been performed for a number of accelerator target configurations.[69]

Dose Conversion Coefficients: Faculty and students in the Health Physics program at ISU are participating in this intercollegiate project with UNLV and other universities (see Task 7 of the UNLV section of this report). Several students are calculating dose conversion coefficients and DCCs.[38]

V. LANL-DIRECTED UNIVERSITY PROJECTS

In FY00 the Accelerator-driven Transmutation of Waste (ATW) Project began as a $9M effort following a decade of laboratory-funded research at Los Alamos National Laboratory. During the ATW Project, Los Alamos National Laboratory contracted with three universities the University of California at Berkeley, the University of Michigan, and the University of Texas at Austin to support ongoing research in transmuter design and analysis, in planning for experiments, and in assessing proliferation-resistance attributes of separations and transmutation technologies. Research projects at these three universities have continued, and they have employed undergraduate and graduate students for several years. In FY02 LANL added two more university programs at North Carolina State University and the University of Illinois at Urbana-Champaign, and ongoing research at Arizona State and the Imperial College of London was folded into the AFCI research program. In FY03, LANL again increased university participation in AFCI research by adding projects at the University of Florida and the Georgia Institute of Technology. In all, LANL supported eighteen students through directed research projects at nine universities. I summarize this research in the following sub-sections.

V.A. University of California at Berkeley

Faculty and students at the University of California at Berkeley have conducted research to evaluate designs of transmuters and to optimize the destruction of neptunium (the isotope of primary concern for long-term storage).[70] Conclusions of analyses of molten-salt and other transmutation reactors are discussed in an earlier paper.[71] In addition, several students have worked on code systems that have directly benefited AFCI research needs while supported by funding from other programs, such as the Nuclear Energy Research Initiative (NERI), the Nuclear Engineering Education Research program (NEER), and Generation IV roadmap and reactor studies projects.[72] One example of this synergy was a project to compare transmuter systems cooled by either lead-bismuth eutectic (LBE) or sodium,[73] and another was a project to evaluate a modular, pebble-bed-type gas-cooled reactor as a transmuter.[74] In FY03, work was concentrated on completing this project including concluding the research on molten salt-based transmuting reactors.[75, 76, 77, 78, 79, 80] In FY03 a new project was initiated to evaluate the impact of transmutation and waste treatment on the design, cost, and operation of a repository.

V.B. University of Michigan

At the University of Michigan, several faculty and students have supported the ATW, AAA, and AFCI Programs with studies for the design of integral experiments as well as evaluations of a variety of technical issues. Faculty members have acted as honest brokers to provide comments and advice during systems studies, reactor studies, and the development of concepts for future experiments. In addition, students have completed considerable work and thesis studies. In one study, mono-energetic neutron sources of sufficiently high energy (e.g. 14 MeV) to contribute to the science of accelerator-driven transmutation in lead and bismuth moderators have been shown to produce flux depressions just below the source energy, such that they would contribute marginally to physics measurements and benchmarking in the energy regime of the depression.[81] This work continued in FY02 with the examination of the ability of standard fast spectrum analysis techniques to capture the details of neutron slowing down in heavy moderators such as Pb and Bi.[82]

As one of the major tasks for the AFCI project at the University of Michigan, Ms. Viktoriya Kulik, a Ph.D. student, has been studying dynamic behavior of accelerator-driven subcritical reactor (ADS) systems. This has involved the development of dynamic models for simulating multiple pulses of spallation neutron sources and methods for determining reactivity in ADS systems. Their emphasis has been on developing computational tools that can accurately and efficiently represent the localized nature of spallation sources in determining the power distribution and reactivity in transient conditions. Ms. Kulik developed numerical algorithms based on a two-dimensional time-dependent diffusion theory code that can accurately account for step changes in localized sources in time to establish a space-dependent dynamic model for simulation of ADS transient behavior.[83] This involves separate treatments for calculating the shape function and amplitude function that can represent prompt space-time variations in neutron flux within the quasi-static formulation. These studies continued in the development of methods to account for spatial dependence in reactivity measurements.[84, 85, 86] The

Reactor Physics Division of the ANS nominated Ms. Kulik s work as one of three finalists for an award.

Other work at Michigan has included the development of a linear reactivity model[87] and extrapolation algorithms for equilibrium cycle analysis of transmutation systems,[88] transmutation in thorium fuel cycles,[89] integral experiments for fuel reaction rate, and advice on the prioritization of research requirements.

LANL technical staff initiated a new project at Michigan in FY02. This project involves the use of proton irradiation to simulate spallation-neutron radiation damage in structural materials that may be used in accelerator-driven systems. This work began with an investigation of the effect of higher gas production at significant doses (several displacements per atom or dpa) to lay a foundation for a full-scale irradiation campaign. It was followed by development of a detailed description of the irradiation campaign (temperatures, dose rates, doses, and He-implantation levels), and finally by conducting irradiation testing on steels at various dpa levels. The first campaign is complete, with proton irradiations of HT-9 and T-91 steels at 3.0, 7.0, and 10.0 dpa having been completed,[90] and a second phase has begun to investigate the effect of proton irradiation on the microstructure, microchemistry and subsequent corrosion and stress-corrosion cracking (SCC) behavior of ferritic-martensitic (F-M) steels for application in spallation neutron environments. Following irradiation, the hardening behavior will be determined with micro-hardness indentation, and previously established relationships will be used to correlate results with yield strength.

V.C. University of Texas at Austin

In one of the two research projects that are ongoing at UT-Austin, proliferation resistance and security metrics have been quantified for separations, fuel fabrication, transmutation, and disposal.[91, 92] They developed of a set of high-level metrics by consulting a number of experts in the field, then subsequently added time-dependence to the methodology as well as uncertainty estimates. A product of this work is an initial comparison of the security metric from transmutation with that from the once-through fuel cycle.[93, 94] The AFCI Blue Ribbon Committee on Nonproliferation has recently requested UT-Austin use the methodology they developed under this LANL-directed project. They were requested to conduct studies of the proliferation resistance of a variety of fuel cycles, and they have presented reports to the AFCI Blue Ribbon Committee.[95, 96, 97] This activity highlights the importance and quality of the research that LANL has directed and UT-Austin has completed for the ATW, AAA, and AFCI Projects. In another project, a UT-Austin student is preparing to conduct a set of cross-section measurement experiments at the LANSCE facility at LANL, then to analyze the measurement results.

V.D. North Carolina State University

North Carolina State University is supporting international collaborations of the AFCI by calculating radiation damage, including production of displacements, helium, hydrogen, and heavier transmutation products, and energy deposition in targets for generation of high-energy spallation neutrons. Faculty and students are examining response in target materials, containment structures, and entrance windows of the target assemblies for the SINQ spallation neutron sources that are under design and development. These targets include the SINQ Targets 3[98] and 5[99, 100, 101] as part of the SINQ Target Irradiation Program (STIP) at the Paul Scherrer Institute (PSI). This is part of an international collaboration that includes the French (CEA), Germans (FZJ), Japanese (JAERI), Swiss (PSI), and technical staff at two U. S. national laboratories: Los Alamos and Oak Ridge (ORNL).°Target 3 was used for the STIP I irradiation, which ended in December 1999, and Target 5 is being used for the STIP III irradiation, which is scheduled to end in December 2003. In addition, they will examine less obvious (and less well studied) mechanisms for the transfer of energy to the irradiated materials and hence the production of displacements. These mechanisms include recoil-atom damage and other interaction products. Finally, they will analyze the effects of the calculated radiation damage on mechanical and other property changes and assess reasonable and safe lifetimes for radiation-damaged components.

V.E. University of Illinois at Urbana-Champaign

Mr. Alan Bolind, a 2001 AAA Fellow at UIUC, has begun a thesis project to investigate impedance spectroscopy as a feasible method of measuring the effects and rates of protective oxide formation on structural materials immersed in lead-bismuth eutectic (LBE), while research staff members at LANL provide advice and collaboration on this effort.[102] Through a contract with LANL, UIUC has purchased components for and constructed a container system (container, piping, connections, thermocouples, heating elements, gases, electronic controls, and LBE) at the Nuclear Engineering Laboratory at UIUC. This system is being used to investigate issues related to corrosion in high-temperature liquid LBE. In this impedance spectroscopy technique, alternating electric currents of various frequencies are being used to measure the electrical impedance of a steel surface that has formed an oxide layer while immersed in liquid LBE. A Phase I Report has been submitted to LANL.[103]

V.F. University of Florida

Technical staff at Los Alamos initiated another new intercollegiate collaboration to investigate the effects of intense proton and neutron irradiation on the oxide layers that are formed on steels in high-temperature LBE systems. Ms. Soroya Benitez, a Florida graduate student, has begun working with the University of Michigan to use their proton cyclotron to irradiate samples that have been oxidized in the DELTA loop (LBE test system) at LANL.

V.G. Other LANL-directed University Research

Other LANL-Directed research is being conducted at three other institutes. A faculty member at the Georgia Institute of Technology acts as a liaison for LANL with the UNLV-lead multi-university Dose Conversion Coefficients Project. Two other institutes are conducting research for LANL s fuels development technical staff. Some of this work is being done at the Arizona State University. In an international collaboration at the Imperial College of London, tools are being developed to model defects in nitride-based nuclear fuels by modeling radiation-induced defects in surrogates.

VI. UNIVERSITY FELLOWSHIP PROGRAM

The University Research Alliance (URA, Amarillo, Texas), which is a consortium of Texas universities, manages the AFCI University Fellowship Program (AFCI UFP) for the DOE-NE. This program is intended to support top students across the nation in a variety of disciplines that will be required to support transmutation research and technology development in the coming decade. The program was described in detail at the 2001 Winter Meeting of the ANS.[104] In the first two years twenty Fellows were selected from highly qualified applicants. The Fellowships were awarded in April of 2001 and 2002 to students who would attend graduate school at 16 universities. Though selection of new students for FY03 Fellowships was suspended because of a shortfall in funding and a delay in the passage of the FY03 budget, the UFP continued to support FY01 and FY02 fellows as they continued their studies. This program has been highly successful, with several universities awarding Master s degrees to Fellows, several of the Fellows continuing on for further post-fellowship graduate education and research, and several working at national laboratories during the past two summers.

The AAA and AFCI Fellows work on a variety of topics as they conduct research for their Master s theses and degrees. Both the FY01 and FY02 Fellows have collaborated directly with technical staff at the national laboratories to formulate their thesis topics so that their research will directly support the research goals of the AFCI Program. To facilitate selection of thesis topics, Academic Research Topics for the Advanced Accelerator Applications Project, which is a summary of research topics that were appropriate for M.S.-level research, was developed.[105] Several Fellows have graduated from the program and gone on to doctoral programs or work at the national laboratories or industry. During the summer of 2003, three of the Fellows chose to work as graduate research assistants (GRA) at three national laboratories: Los Alamos, Argonne (ANL), and Oak Ridge. GRAs worked on a variety of projects, for instance:

- at LANL, on separation of cesium and strontium from the streams of partitioning processes;
- at ORNL, on characterization of fluoride residues from separations processes; and
- at ANL-West, on modeling of dispersion fuels for transmutation of plutonium in LWRs.

The breadth of interests and research topics are demonstrated by the work, publications, and presentations that the Fellows are generating. The following sub-sections include descriptions of contributions of these fellows to AFCI research needs.

VI.A. Progress and Accomplishments of FY02 Fellows

Ms. Lisa Cordova, a nuclear engineering major at the University of New Mexico, has been working with Sandia National Laboratories investigating elastic scattering models for generating neutron cross sections for accelerator-driven transmutation.[106]

Ms. Jennifer Ladd-Lively is in the Chemical Engineering Program at the University of Tennessee, Knoxville. She is conducting research in conjunction with ORNL developing flow sheets for fuel separations via fluoride volatility processing.[107, 108]

She also worked at ORNL as a graduate research assistant during the summer of 2003.

Mr. William Wieselquist is investigating the impact of cross-section uncertainties on nuclear fuel assembly design while majoring in reactor physics (nuclear engineering) at North Carolina State University.

Mr. Thomas Carter, a nuclear engineering student studying at the University of Florida, is examining the feasibility of mixed-carbide fuels for use in transmutation systems.[109]

At the University of Texas-Austin Mr. Mike Gregson, a nuclear engineering student, used radiation transport codes to conduct a full core analysis of an ATW prototype for nuclear cross section data. He is also contributing to a LANL-directed university research project (see previous entry in section V.C.).

Mr. Matt Sowa in the University of Michigan Nuclear Engineering Department is conducting an investigation of pyrochlore and zirconia as inert matrix target materials for transmuting transuranics.

At the Georgia Institute of Technology, Mr. Lee Van Duyn, a mechanical engineering major, is evaluating the mechanical behavior of a metal-matrix dispersion fuel for plutonium disposition.[110] He worked at Idaho National Laboratory this summer with AFCI fuels processing researchers.°

Mr. Frank Szakaly, who is in nuclear and radiological engineering at Texas A&M University, is studying thorium-based nitride fuels for used fuel transmutation.[111]

VI.B. Progress and Accomplishments of FY01 Fellows

Ms. Kamilah Turner, a chemical engineering student at the University of Michigan, earned the M.S.Ch.E. degree (June 2003) while studying chemical vapor deposition of molybdenum metal coatings on silicon nitride substrates and while working with and for the National Technical Director for Separations Technology.

Ms. Jessica White is studying physics at the University of Texas at Arlington. She has been conducting a computational analysis of americium-bearing nuclear dispersion fuels for the fuels development technical staff at ANL-W.

Mr. Thomas Roddey earned a unique degree while studying Energy Policy & Nuclear Engineering at the University of California at Berkeley. He was awarded the M.S. (Energy and Resource Management) in May 2003, for conducting a comprehensive risk assessment to research the correlation between funding for proliferation abatement and waste management projects and the risks associated with political instability in countries currently thought to be without nuclear weapons capability

Mr. Thomas McKittrick has conducted research to measure the total and differential cross sections of erbium while studying nuclear engineering at the University of Massachusetts.

Texas A&M University graduated Mr. Preston Pratt with the M.S.N.E. degree in Dec. 2002. He developed a three-dimensional simulation of a thermal experiment conducted on a target model concept for an accelerator-driven system.[112]

Mr. James Platte studied in the Department of Nuclear Engineering and Radiological Sciences at the University of Michigan and earned the M.S.N.E. degree in Dec. 2002. In his research he used the STAYSL code to unfold spectra measured in the LANSCE accelerator-driven system at LANL.

The Ohio State University graduated Mr. Benjamin Milliron with the M.S.N.E. degree in December, 2002. He worked on a project for ANL examining a fluoride volatility process for extracting technetium from transmuted used nuclear fuel.[113]

Mr. Alan Bolind completed the fellowship program at the University of Illinois at Urbana-Champaign in August. He has recently passed his Ph.D. qualification exams in the nuclear engineering program, and will soon begin the doctoral program. He is also currently working on a Directed University Project for Los Alamos, examining target/window and blanket coolant materials exposed to lead-bismuth eutectic (see the previous entry in section V.E.).[102, 103]

VI.C. Fellowship Successes Before FY03

This section describes successes of the Fellowship program that occurred prior to this fiscal year. This information is included herein because it was not reported previously.

The Massachusetts Institute of Technology awarded the M.S.N.E. degree in May, 2002, to Ms. Juliet Leigh Outten for her work on the development of a master logic diagram and event trees for systems modeling of an accelerator driven system.

Mr. Coy Bryant, from the University of Texas at Austin, earned the M.S.N.E. degree in May 2002 while developing computer models for ANL and for performing a sensitivity analysis of variables used for optimizing flow sheets for actinide transmutation. He developed models for the UREX solvent extraction process.

VII. LABORATORY RESEARCH ASSISTANTS AND INTERNS

The national laboratories employ students, from high school through undergraduate to Ph.D. to provide administrative assistance and to conduct critical scientific research. Most graduate research assistants (GRA) conduct research during the summer, however, several students are supported during other portions of the year, and Ph.D. students may work at the laboratories year-round.[114] This year, 3 of the AFCI national laboratories supported 19 undergraduate and graduate students directly during the past year (12 at LANL, 6 at ANL-West, and 1 at ORNL). This total includes three of the AFCI Fellows (Mr. Szakeley, Ms. Ladd-Lively, and Mr. Van Duyn) who were mentioned previously in the AFCI UFP Students section of this report. Ms. Rhonda Karen Corzine is working year-round on her Ph.D. at Los Alamos measuring cross sections for the production of ^{148}Gd for accelerator target facilities. [115]

VIII. UNIVERSITY PROGRAMS CONTRIBUTIONS TO INTERNATIONAL COOPERATION

Through multi-university and multi-laboratory collaborations, universities are conducting research at, in collaboration with, and/or for international organizations. Universities that have contributed to international collaborations and that will be discussed in this section include UNLV, ISU, Michigan, and NCSU. International organizations involved in these collaborations with AFCI-supported university programs include:

- V. G. Khlopin Radium Institute, St. Petersburg, Russia (KRI)
- Karlsruhe Lead Laboratory, Germany (KALLA)
- Institute of Physics and Power Engineering, Obninsk, Russia (IPPE) and the International Science and Technology Center (ISTC)
- Imperial College of London, UK (ICL)
- Tbilisi University, Republic of Georgia (TU)
- Paul Scherrer Institute, Switzerland (PSI)
- Atomic Energy Commission of France, Cadarache, France (CEA)

VIII.A. International Contributions of the UNLV TRP

At UNLV, which has become the lead university for transmutation research in the U.S., two research projects involve interaction with international organizations. In addition, UNLV is building infrastructure in an international collaboration, and they have become a member of the ISTC. In one project, UNLV contracted with the KRI to develop a 60-element ^{3}He detection system surrounding a cylinder of lead for neutron multiplicity measurements. This device was designed to be inserted into particle beams to measure the spatial and directional dependence of multiple-neutron generation events (neutron multiplicity) in accelerator target/blanket materials.[37] This neutron multiplicity measurements system was constructed at the KRI with $112.5 k of UNLV TRP funding, then it was shipped to UNLV, where it has been set up for calibration and validation. The estimated value of the detection system is $1 M. In addition, Mr. Dean Curtis, an undergraduate student at UNLV, has visited KRI in St. Petersburg to collaborate with Russian scientists in numerical modeling of systems for predicting measurement performance, and a $11.1 k follow-up contract has been written to support computational work the KRI.

In another UNLV TRP international collaboration, UNLV has assumed responsibility for an ISTC project, has taken over the contract from Los Alamos, and has acquired a lead-bismuth cooled target for proton accelerators. The device, which has been dubbed TC-1, is being installed in a laboratory at UNLV where it will be used for thermal hydraulic and material corrosion experiments. When the UNLV LBE lab has been completed, the device will be set up and qualified by scientists and engineers from IPPE in Obninsk, Russia. This work is supported with $186 k of UNLV TRP funds over 25 months. UNLV faculty members have also established a relationship with scientists at KALLA, and have formed an international advisory committee on lead and lead-bismuth systems.

Finally, UNLV faculty and students are working with the KRI to develop waste forms for the back end of fluorine-based separations processes.[6] One concept is the use of the mineral fluorapatite as a waste form following chemical processing of used nuclear fuel. Another concept is the immobilization of fission iodine by reaction with a Fullerene-containing carbon compound (FCC) and insoluble˚natural organic matrix (NOM). Researchers at the KRI have proposed that the iodine-loaded FCC material, when combined with ceramics, is stable enough for use as a long-term storage form, and may also be a matrix target for transmutation of iodine. For this work UNLV has established a two-year project at the KRI with $152 k per year of TRP funding.

VIII.B. International Contributions of the ISU-IAC

The Idaho State University, which is the second largest component of AFCI university programs, is collaborating with students and scientists from two international organizations. In one project, students from Tbilisi University in the Republic of Georgia are working on a project to evaluate dose conversion coefficients for rare isotopes that are produced in high-energy spallation targets.

Another project has been initiated to use high-energy linear accelerators to drive nuclear assemblies in Dubna, Russia. This work involves accelerators and reactors at the KRI as well as more powerful accelerators that will be installed at ISU-IAC in the future. In addition, this project may involve measurements of pure isotopes at KRI.

VIII.C. International Contributions of LANL-Directed University Projects

Three universities have been involved in research to support LANL s requirements:

NCSU: See the previous description in the LANL-Directed University Projects section of this report. The NCSU work is entirely for the support of international R&D at the Paul Scherrer Institute.

University of Michigan: Several faculty and students have compared neutronics tools to validate design methods; these codes have included those in use in international programs. In addition, they have been studying dynamic behavior of accelerator-driven subcritical reactor (ADS) systems, such as the recent MUSE experiments and the future TRADE program (TRIGA Reactor Accelerator Driven Experiments program in Italy). This has involved the development of dynamic models for simulating multiple pulses of spallation neutron sources and methods for determining the reactivity in ADS systems. Their emphasis has been on developing computational tools that can accurately and efficiently represent the localized nature of spallation sources in determining the power distribution and reactivity in transient conditions. A Michigan student developed numerical algorithms based on a two-dimensional time-dependent diffusion theory code that can accurately account for step changes in localized sources in time to establish a space-dependent dynamic model for simulation of ADS transient behavior.[83, 84] This involves separate treatments for the calculations of the shape function and the amplitude function that can represent prompt space-time variations in neutron flux within the quasi-static formulation. These studies continued in the development of methods to account for spatial dependence in reactivity measurements. The method was recently used to correct measurement results from the MUSE program.

Imperial College of London: one faculty member and one student are developing tools to model defects in nitride-based nuclear fuels under a $60 k contract for the AFC Fuels Research program. In this international collaboration, a capability to model radiation-induced defects in surrogates will provide the capability to predict the performance of nitride fuels. In addition, the student from ICL worked at LANL during the summer of 2003.

VIII.D. Total Value of International Contributions from AFCI University Programs

The estimated value of these university-international collaborations would be more than $3 M for the same research, development, and construction of equipment to be conducted at U.S. national laboratories.

IX. PUBLICATIONS AND PRESENTATIONS

In the short time that the ATW, AAA, and now AFCI university programs have existed, many papers have been published and many presentations have been made. This year s annual university report alone includes more than one hundred citations of papers and presentations that were generated through academic research. A University Programs poster was presented at the imbedded AccApp 03 conference during the 2003 Annual Meeting of the ANS in San Diego, CA.[116] Another poster presentation by an AFCI-funded student was selected as the best poster at AccApp 03.[37] Colloquia highlighting the AFCI Program were presented at the University of Missouri at Rolla and at the University of Missouri at Columbia. The AFCI program was also highlighted in the Fall 2003 issue of the UNLV Alumni magazine.[7]

X. FUTURE GROWTH

Expansion of academic collaborations for the AFCI Program in FY04 and beyond depends on projected budgets; however, the U.S. Congress has demonstrated their interest in these programs by earmarking $3 M for directed university research in draft legislation for the FY04 budget for nuclear energy R&D. An increased budget may allow these programs to expand and others to be added. One program that will likely be added is a Doctoral Fellowship Program, which will expand the research value of the AFCI Master s-level fellowship program. With growth in the UNLV TRP, ISU-IAC, AFCI Fellowships, and Directed University Research, university collaborations could reach the order of $10 M during FY04.

XI. MEETING THE GOALS

In the introduction I described the goals of the AFCI Project: to develop transmutation technology to reduce the radio-toxicity, volume, and heat load of waste from used nuclear fuel. This could impact the design, operation, and cost of a deep geological repository as well as impact the need for a second repository in the near future. In addition, this program s goals include revitalizing our nuclear infrastructure as well as a resumption of an international leadership role. With the transition to the Advanced Fuel Cycle Initiative (AFCI), our University research supports all of these goals while expanding on and leveraging other DOE/NE programs such as the Nuclear Energy Education Research Program (NEER), the Nuclear Energy Research Initiative (NERI) as well as International NERI (I-NERI), and reactor research and development programs such as Generation IV and Next Generation Nuclear Plant (NGNP). Much of the research and development that is being conducted for the AFCI Program will support the development of Generation IV concepts and advanced nuclear systems. With 140 students supported this fiscal year, and the expectation of even more in 2004, the contribution to the U.S. nuclear infrastructure is obvious. With the program now in its fifth year, the AFCI is building a constituency among academia, and universities are graduating many students with advanced degrees as well as undergraduate students who are familiar with the project. In addition, U.S. participation in international collaborations is increasing as a result of the many research projects supported by AFCI funding. This will demonstrate to the international community an expanding major role for the U.S. in this technology. AFCI University Programs will continue to strongly support the mission and goals of the AFCI Program in the future.

XII. SUMMARY

The Advanced Fuel Cycle Initiative Program will require a large cadre of educated scientists and trained technicians in the next decade or beyond. Other applications of nuclear science and engineering also require increased academic and national infrastructure and student populations. The AFCI Program includes university faculty and students in various phases to support the infrastructure requirements of nuclear energy, science and technology fields as well as the special needs of the DOE transmutation program. These AFCI University Programs complement other DOE/NE programs such as the NEER, NERI and I-NERI projects, and reactor research programs like Gen-IV and NGNP by connecting students to nuclear research projects in a wide variety of academic disciplines. In this paper we described university programs that have and are supporting the R&D necessary for the AFCI Program. These ongoing programs include the UNLV Transmutation Research Program, the Idaho Accelerator Center at the Idaho State University, Directed University Research, the University Fellowship Program, and other efforts. The AFCI Program is well poised to contribute to the future education of nuclear scientists and engineers while conducting research that is essential to the success of the project. We expect AFCI University Programs to grow substantially in the coming years.

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